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CEREAL SMUTS

AND

THEIR CONTROL

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FOREWORD

SMUT diseases are responsible for very considerable loss of cereal grain in this country every year, Bunt of wheat, in particular, being the cause of loss of many thousands of bushels annually. Since it is possible, by fairly simple methods and at very moderate cost, either to avoid all loss caused by a given smut disease or to reduce the loss to a minimum, the Ministry has prepared this Bulletin to guide farmers as to the means that are at their disposal to combat these troublesome diseases. Attention has recently been given to the use of dry copper carbonate for the treatment of wheat against Bunt, and this new method is well worthy of extended trial, although the older, wet methods are still effective.

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CEREAL SMUTS AND THEIR CONTROL

The Smut diseases of cereals are caused by parasitic fungi, which attack the living tissues of the plant and eventually produce in them black, soot-like, more or less powdery masses of material, made up of myriads of spores. The latter are the reproductive bodies of the Smut fungi and are equivalent to the seeds of flowering plants. The Smuts are distributed by the dispersal of these spores, and they are the sole source from which infection with Smut arises.

A few of the cereal Smuts may affect any or all of the above-ground organs of the host plants. This is true, for instance, of the so-called Flag Smut of wheat, and of the Stripe Smut of rye; fortunately, however, the former is still unknown in this country and the latter is extraordinarily rare and of no economic importance here. The Smuts that are of importance here confine their attacks almost entirely to the ears and grain, and the general effect of such attacks is the conversion of the grain into a black mass of spores, and the partial or total destruction of other parts of the ear. Occasionally, however, patches of Smut may occur on the leaf sheath which surrounds the ear before it emerges.

The damage done is measurable, not only by the amount of grain actually destroyed, which is often very large, but also, in many cases, by the diminished value of the healthy grain, which becomes blackened and contaminated by the spores that adhere to its surface. In Bunt or Stinking Smut of wheat such grain has a fishy odour, and this seriously detracts from its market value.

Although to a casual observer all the cereal Smuts appear to be more or less alike, closer study will reveal certain important differences between them. Two classes may be distinguished, viz., *covered* Smuts and *loose* Smuts. In the former, each black spore-mass is, at the outset, more or less firm. It remains intact for a considerable time, being enclosed in the somewhat altered skin of the grain or kernel, and being further protected by the survival, at least partial, of the chaffy scales that surround the grain (see Figs. 1, 4, and 7). In loose Smuts, however, owing to the greater amount of destruction of the skin of the grain and of the surrounding envelopes, each mass soon loses its compactness; and the spores of which it is composed are readily washed away by rain or blown off by the wind.

Hence, before long, little or nothing may be left of a loose-smutted ear except the bare axis or stalk on which the diseased grains and the accompanying envelopes were borne (see Figs. 3, 5 and 6).

There are other and less obvious ways in which cereal Smuts differ, but these need not be discussed here. It is, nevertheless, very important to realize that, associated with the differences mentioned, there are essential dissimilarities in the behaviour of certain of the cereal Smut fungi, especially as regards the way in which infection of the host plant occurs; these have a most important bearing on the problem of successful control and are referred to later on.

The various Smuts of cereal grains (with one possible exception*) are specific; that is to say, the different kinds that attack one particular cereal, attack that cereal alone, and cannot infect others. In some cases the connexion between host and parasite appears to be even closer than this, for recent researches show that so-called "biological species" of Smuts exist; that is, species that are confined to particular varieties of a single kind of cereal. Varieties of one and the same cereal may be immune from infection by one particular "biological species," although liable to attack from others. It will scarcely be surprising, then, to find that the Smuts that attack plants other than cereals, such as those of various grasses and other wild plants, as well as those of cultivated plants, such as onion and leek Smut, cannot attack cereals.

BUNT OR STINKING SMUT OF WHEAT

Thousands of bushels of wheat in this country are lost annually or rendered unfit for normal use through this disease,† but these losses are avoidable and can be prevented by seed disinfection carried out as described below. Some varieties of wheat are believed to be more resistant to attack than others, but no exact data on this point are available for Britain.

Description of the Disease.—In the early stages of the growth of the crop the disease is not easily, if at all, recognizable. It has sometimes been stated that, owing to their darker

* The exception is the Loose Smut of rye, which does not appear to have been recorded as occurring in this country. It would seem, as a result of cultural studies and cross infection experiments, that the fungus which causes this Smut is identical with that which causes the Loose Smut of wheat.

† The names of the two fungi that cause Bunt in wheat are *Tilletia Caries* and *T. foetens*. The former is the common one in this country; the latter is seldom met with.

green colour and apparently more vigorous condition, plants that will be bunted can be picked out by experienced and acute observers; but such symtoms are not infallible and they are not evident in every variety. After the ears have emerged the difficulties are not quite so great. Bunted ears are frequently narrower than healthy ones, and they are borne on shorter haulms and tend to be bluish in colour. As ripening proceeds, the chaffy scales in a bunted ear become pushed somewhat apart (Fig. 1) because the deformed bunted grains are plumper, but shorter, than normal grains. Bunted grains are brownish in colour, and internally they consist wholly of a black mass of spores, more or less greasy at first and having a distinctly fishy odour; hence the name " Stinking Smut." Some of the bunted grains may burst and show their black contents before harvest, but most of them remain intact. They are sometimes known as " butts " (Fig 2).

Bunted and healthy ears are harvested and thrashed together. During thrashing, many of the bunted grains burst open, and clouds of spores are liberated from the thrashing machine into the air. Some of the remaining spores adhere to the exterior of the healthy grain and accompany it into the sacks, while others remain in the machine and serve to contaminate the next lot of wheat thrashed by it. As to the bunted grains that do not burst during thrashing, some are removed during the sifting and winnowing processes in the machine, but many pass out whole with the grain itself. The thrashed produce of a bunted crop therefore consists of healthy grains coated with a varying abundance of Bunt spores, together with unbroken bunted grains or " butts." During subsequent handling, more of these " butts " may become broken open, thus liberating the spores and resulting in denser contamination of the grain. The sacks or other containers into which such grain is put will also become contaminated and, if subsequently used to hold clean grain, will contaminate this also.

Mode of Infection of the Wheat Plant.—When contaminated grain, that is, grain with Bunt spores adhering to its surface, is sown, germination of the grain and of the spores occurs underground more or less simultaneously. Each grain produces rootlets first, and then a sprout. Each spore produces a short, tubular out-growth, from the tip of which secondary spores are developed in considerable quantity. When the sprout of the grain is about half-an-inch long or less, infection occurs by the entrance into the sprout of a germ-tube developed from one of the secondary spores. Once within the young seedling wheat

plant, the fungus develops its spawn or mycelium there. This is not produced in any very great quantity, and its presence does not markedly affect the health or appearance of the developing wheat plant. The mycelium keeps most active in the regions just behind the growing-points of the haulms, and maintains its position as the haulms grow upward. When the time comes for the formation of the grain, the food provided by the wheat plant for grain development is seized upon by the fungus, and is utilized for the production of the black masses of spores, which fill the skin of the grain as already described.

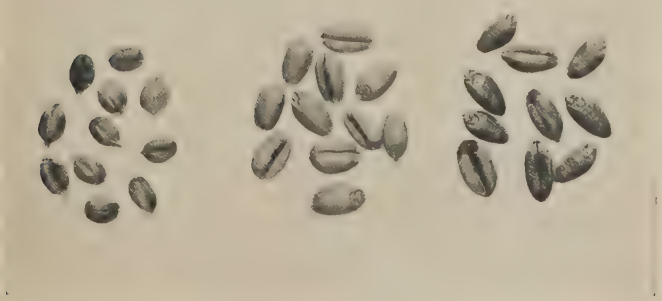
From the bunted grain the healthy seed-grain becomes contaminated with spores; infection of the young wheat seedling in the soil takes place in due course, and so the cycle repeats itself. There is no direct infection from wheat plant to wheat plant in the crop at any stage of its development, hence the disease does not spread in epidemic fashion as Rusts often do.

Prevention of Bunt.—Bunt can be prevented by suitable disinfection of the contaminated seed, a process usually known as *pickling*. It is the spores adhering to the outside of the grain that, for practical purposes, may be looked on as the sole source of infection of the crop. In certain exceptional circumstances—as, for instance, if wheat is sown on land that has quite recently become heavily contaminated with Bunt spores, blown there perhaps from a thrashing machine—there may be some danger of infection from spores already in the soil, but trouble of this kind is quite unusual in this country. Spores that pass through the alimentary tract of a farm animal are mostly killed in the process, and spores in the manure heap germinate readily and are quickly killed off. Danger of infection from this source may, therefore, be regarded as negligible.

Unless it has become contaminated from the thrashing machine or by some other means, seed grain from a perfectly healthy crop does not, of course, require to be pickled. The presence of even a few bunted grains amongst the seed, however, indicates serious contamination, even if the bulk of it is not manifestly blackened. At seed testing stations bunted grains, if present, are readily detected during the purity test of a sample, and at certain stations senders of samples are advised on this point as a matter of routine. If bunted grains are present in considerable numbers it is probably wiser not to use such grain for seed; this precaution also applies to grain that is badly blackened and has a fishy smell, as well as to grain that has been damaged mechanically or otherwise, since a liquid

Healthy. Bunted. Bunted.

FIG. 1.—One healthy and two bunted ears of wheat.



Butts. Clean. Contaminated.

FIG. 2.—Bunted grains or "butts" on the left, clean grain centre, grain contaminated with adhering spores of the bunt fungus on the right.

FIG. 3.—Ears of wheat showing various degrees of attack by Loose Smut.

FIG. 4. FIG. 5.

FIG. 4.—Barley: Covered Smut. The smutted grains are still unbroken.

FIG. 5.—Barley: Loose Smut. The smutted grains have disintegrated and the spores have, for the greater part, been blown away.

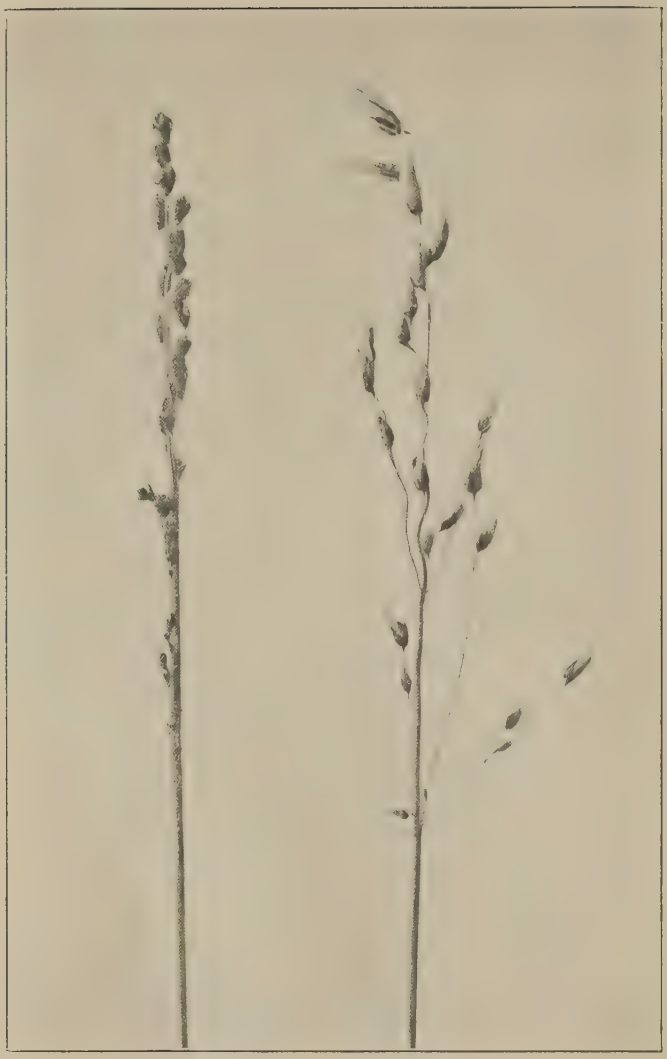


Fig. 6. Fig. 7.

Fig. 6.—Oats: Loose Smut. The smutted grains are naked and exposed.

Fig. 7.—Oats: Covered Smut. The smutted grains are still covered by the glumes (chaff).

pickle may further injure it. If bunted grains are absent and if any doubt exists as to whether seed is contaminated or not, the matter can be settled with the aid of a microscope by those accustomed to use one. In the absence of such examination it is probably wise to assume contamination, and accordingly to pickle the grain.

From the Official Seed Testing Station for England and Wales, the sender of a sample of wheat for testing for purity and germination is advised if the sample contains bunted grains, without additional charge. With samples that, though free from bunted grains, may nevertheless be contaminated with Bunt spores, the Station is prepared, on request, to go further. A microscopical examination of such samples will be made, and a report issued as to contamination with, or absence of, Bunt spores; an additional fee of 2s. per sample will be charged for this examination. A similar special microscopical examination will also be made on samples not sent for germination tests, at a fee of 2s. per sample. Samples forwarded for this purpose should each be at least 4 oz. in weight, and each sample must be enclosed in a separate, strong, clean envelope. The samples should be sent either separately or in a well made up parcel, addressed to the Chief Officer of the Seed Testing Station, Huntingdon Road, Cambridge.

Pickling with Copper Sulphate (Bluestone).—Sprinkling with, or steeping in, a solution of copper sulphate (bluestone) is one of the oldest methods of pickling wheat against Bunt. To-day, perhaps, it may be looked on as an old-fashioned and rather out-of-date method, because of the newer and better formalin treatment described below.* Its great disadvantage is that it frequently causes serious injury to the germination of the grain. The amount of injury depends on various factors: all varieties of wheat are not equally sensitive to the treatment. Seed of one and the same variety may react differently according to whether the season of growth and harvest was favourable or not for its proper development, and whether the grain was damaged or not during thrashing, and so forth. Whether injury will result or not also depends on the strength of the solution used, as well as on the care exercised in carrying out the pickling process, and on the rapidity and thoroughness of subsequent drying. It is impossible to lay down exact rules

* For the results of experiments with bluestone and formalin see articles by Messrs. Salmon and Wormald in the Ministry's *Journal*, Vol. 27, 1920/21, p. 1,013, and Vol. 29, 1922/23, p. 722.

that will fully cover every eventuality, but the following procedure may be regarded as a standard one for copper sulphate pickling in ordinary circumstances.

The seed should be placed in a heap on a clean floor. It should be sprinkled or sprayed uniformly with a solution of 2½ lb. of copper sulphate* dissolved in 10 gal. of water, preferably rain or soft water. Rather more than 1 but less than 2 gal. of this solution will be required for every 4 Imperial bushels of seed. Whilst being sprinkled, the seed must be mixed thoroughly by continuous shovelling, the aim being to secure that each grain becomes uniformly moistened with a thin film of the solution. As soon as this has been accomplished, the grain should be raked out into a thin layer so that it may dry as rapidly as possible. It may be sown as soon as it is dry. Care must be taken to see that the grain does not become re-contaminated after being pickled.

Sometimes seed wheat is steeped in copper sulphate solution instead of being sprinkled with it, and in these circumstances any bunted grains that are present rise to the surface and can be skimmed off. The strength of the solution may be that mentioned above, and the time of steeping 5 minutes. After steeping, the solution is run off and the grain spread to dry as in the previous method. Although steeping may be rather more efficient than sprinkling, there is more risk of damaging the vitality of the grain.

Pickling with Formaldehyde.—Formaldehyde is preferable to copper sulphate for pickling wheat, since disinfection with it is generally more complete, and injury to the grain usually negligible. Only if the treated seed is sown in very dry soil, or if there is considerable delay after pickling and before sowing, is damage likely to occur.

Formaldehyde is a gas and is sold as an approximately 40-per cent. solution in water, under the name of formalin. The dilution required is 1 pint of formalin to 40 gal. of water; or, ½ fluid oz. (1 tablespoonful) per gal.† The seed should be placed in a heap on a clean floor, uniformly and carefully

* Copper sulphate of at least 98 per cent. purity should be used. "Agricultural" copper sulphate and other pickling materials with fancy names should be avoided, owing to the risk of their being impure or inefficient.

† A somewhat more dilute solution has also given good results, viz.—1 pint of formalin to 60 gal. of water or 1 fluid oz. to 3 gal., 1 tablespoonful in 1½ gal. The capacity of domestic tablespoons varies somewhat; large ones will hold about ¾ fluid oz.

sprinkled or sprayed with the solution, and constantly turned over and over during the process to ensure the uniform moistening of every grain. From 1-2 gal. of solution will be required to moisten 4 Imperial bushels, but it must not be allowed to form a pool under the heap, so that the grains might soak.

After the sprinkling and shovelling, the grain must be formed into a heap and be well covered with sacks that have previously been wetted with the solution. The covered heap must then be allowed to stand undisturbed for *four hours,* during which time the formaldehyde completes the disinfecting process. The sacks should then be removed and the heap raked out into a thin layer so that it may dry as rapidly as possible. Care must, of course, be taken to see that the pickled grain does not become freshly contaminated* from any source, and it should be sown as soon as possible after it is dry, at latest within two days.

Pickling with Powders.—Moistening seed grain with water or with solutions is always troublesome and is to some extent a risky process. The idea of avoiding this by the employment of dry powders to disinfect wheat is not a far-fetched one; nor, indeed, is it entirely new. The advantages of such a method will be obvious and need not be discussed here. Only in quite recent years, however, has this method been used on a field scale. In fact, so far as this country is concerned powder-pickling is only just emerging from the experimental stage. The credit for the introduction and practical trial of the method must be given to plant pathologists in Australia, but in the last few years it has also been employed with considerable success in America. It must be admitted that powder-pickling has not proved completely successful in suppressing Bunt when the seed is very heavily contaminated with spores, but even the wet treatment with copper sulphate or with formalin does not always give complete success with such seed.

The substance that has been used most often is very finely-powdered copper carbonate. About 2 oz. are required per Imperial bushel of seed. It must be applied so as to coat the exterior of the grain thoroughly and evenly. This may be done by churning the seed and powder together in a revolving barrel provided internally with suitable baffle boards, or by placing them in a powder-proof sack or bag, and shaking the contents vigorously whilst holding the sack by the four corners. Great

* The most serious source of re-contamination is probably unbroken "butts"; these contain myriads of still viable spores and they readily burst on subsequent handling of the grain.

care must be taken to see that the operators do not get the dust into their mouths or nostrils. The seed may be sown at any time after treatment, and no special precautions against re-contamination are required. Two seasons' trials recently carried out by Advisory Officers in England and Wales showed that, on the whole, pickling with copper carbonate powder was just as efficacious in preventing Bunt as was pickling with copper sulphate solution or with formalin. Farmers therefore need not hesitate to give this new method a thorough trial. An account of these trials will be found in the Ministry's *Journal* for August, 1930, pp. 429-439.

Seed treated with copper compounds either in the dry or wet way is probably best regarded as poisoned, and therefore, if for any reason not sown, as not suitable for feeding purposes; although two trials have shown that poultry fed with pickled grain for a few days, or with such grain mixed with untreated grain, do not appear to suffer.

LOOSE SMUT OF WHEAT

This kind of wheat Smut* can be recognized in the crop much more readily, and at a considerably earlier date, than is possible with Bunt. The black, smutty ears become conspicuous as soon as they emerge from the sheaths of the topmost leaves. As in Bunt, the affected grains become converted into masses of Smut spores. These masses, however, are not firm and compactly held together by the skin of the grain as in Bunt, but soon become loose and powdery, and are easily washed away by rain, or blown away by the wind (Fig. 3). Ultimately nothing may remain of the smutted ear except its bare central axis. There is no fishy smell as in Bunt.

Method of Infection.†—The spores are carried away from the smutted ears by the wind, and are deposited on healthy ears in the crop at flowering time. Any spores that fall on the exposed, feathery stigmas germinate there and produce mycelium, which forthwith enters the incipient grain. The entry of this mycelium has no visible effect on the grain, which enlarges and ripens apparently normally. It is, therefore, not

* The name of the fungus that causes Loose Smut of Wheat is *Ustilago Tritici*.

† The mode of infection described here is that generally held at present as being the sole means by which the smut fungus finds entry into the plant. Further research, however, may necessitate some modification of this view.

possible, without difficult microscopical internal examination, to distinguish an infected grain containing the parasite within it from a perfectly healthy one.

Healthy, and internally infected, grains are harvested, thrashed and sown together. When an infected grain begins to germinate, the hitherto dormant mycelium within it awakes and proceeds to grow. As the wheat plant grows, the mycelium keeps pace with it, remaining most active, as in Bunt, just behind the growing-points of the haulms. The presence of the parasite within the host, however, cannot be discerned from any outward abnormal symptoms in the plant itself. When the grains are about to be formed, and before the emergence of the ear from the sheath, the fungus proceeds to produce in them its black masses of spores and, with the subsequent distribution of the spores by the wind, and infection of the incipient grain through the stigmas of the flowers, the cycle is completed.

In attempting to prevent Loose Smut therefore, we have to deal with the parasite in the form of mycelium *within* the grain; whilst in Bunt, as already explained, the parasite is entirely external and adheres, in the form of spores, to its surface. In Loose Smut the grain is *infected,* in Bunt it is only *contaminated.*

Prevention of Loose Smut.—The problem—a difficult one—is to kill the mycelium within the grain, without injury to the vitality of the grain itself. No external application of fungicides, it is clear, will be of the slightest use, but it has been found possible by suitable heat-treatment to accomplish the end in view.

Seed grain from a wheat crop affected with Loose Smut should be put into a sack, incompletely filled to allow for some subsequent swelling. The sack should then be placed in a vessel of cold water and arranged so that the level of the water is slightly above that of the grain in the sack. The sack should be raised and lowered a few times to ensure that the water permeates the entire contents and surrounds every grain. After standing for four hours, when some swelling will have occurred and the dormant mycelium within the infected grains will have become more susceptible to the action of heat, the sack should be lifted out and the cold water allowed to drain away from it for a few minutes. It should then be submerged for *ten minutes* in a tank of hot water. The secret of success is to have, and to keep, the hot water at exactly the right temperature during this period, and a thermometer is absolutely necessary for guidance.

The temperature must not be below 52° C. (125° F.), or the mycelium will not be killed. It must not exceed 54° C. (129° F.), or serious injury to the germination of the grain will result. When the cold sack of grain is plunged into the hot water the temperature of the latter will of course immediately be reduced, and this must be adjusted by the addition of boiling water in sufficient quantity to raise it to the required degree. Care must also be taken to ensure that the temperature within the sack —that is, the temperature to which the whole of the grain is exposed, reaches the required minimum and remains between it and the maximum for the required ten minutes. The contents of the sack should then be turned out on a clean floor and spread in a thin layer so that the grain may dry as quickly as possible; it should be sown when dry.

It will be clear from the above that successful treatment of seed wheat infected with Loose Smut is not easy to accomplish; and the farmer should endeavour to obtain seed from a crop wholly free from this Smut and thus avoid the necessity for treatment.

COVERED SMUT OF BARLEY

Of the two kinds of Smut that attack barley, the covered one* is by far the more important in this country, and the losses caused by it are often severe. An affected plant cannot readily be detected in a crop until the ear begins to emerge from the sheath of the topmost leaf of the plant. Emergence is not infrequently imperfect, and the diseased ear may remain partially enclosed by the sheath for some time or even permanently. Usually, every ear of a diseased plant and each grain in the ear become affected; and the substance of the grain is converted into a firm, blackish mass of fungus spores. This mass is held together by the disorganized skin of the grain assisted by the altered chaffy scales (pales), which in ordinary varieties of barley are adherent to the kernel. The awns that form the beard may remain intact or they may become more or less withered and destroyed. An ear of barley affected with Covered Smut is illustrated in Fig. 4.

The diseased ear, as a whole, remains practically intact until harvest time, and the fungus spores, therefore, are not previously distributed to any extent by the wind or other agencies. Diseased and healthy ears are harvested and thrashed together. During the latter process the smutted ears and grains become

* The name of the fungus that causes the Covered Smut of barley is *Ustilago Hordei*.

broken up and disintegrated. The spores that are thus liberated are, to some extent, blown away from the thrashing machine; but a large number of them adhere to the surface of the healthy grain and thus discolour and contaminate it. Some of the spores remain in the thrashing machine and serve to contaminate crops of barley thrashed subsequently.

It will be seen that, so far, the course of the disease is almost exactly similar to that followed in Bunt of wheat; indeed, the later stages of the two diseases also run on parallel lines, and the methods of prevention are similar in principle. Although with Covered Smut of barley there are no actual " butts " or bunted grains such as occur in wheat Bunt, yet irregular, smutted fragments of the ears and grains of barley do pass out of the thrashing machine with the healthy but spore-contaminated grain; and these fragments may, of course, serve as sources of further contamination.

When contaminated barley grain, that is grain with Smut spores adhering mechanically to its surface, is sown, the spores and the grain germinate more or less simultaneously. While the barley plant is very young and still wholly below ground, it becomes infected with the fungus. This occurs by the penetration of the youngest leaf by a germ-tube produced from a secondary spore that has developed from the germ-tube of one of the primary Smut-spores. Having gained an entry, the fungus develops its spawn or mycelium within the barley plant in a manner similar to that described for the wheat Bunt fungus. The plant appears to suffer no harm until development of the ear begins Then, instead of normal grains, the masses of Smut spores, already described, are produced, and the cycle is once more completed after harvesting and thrashing.

Prevention of Covered Smut of Barley.—Covered smut of barley cannot be cured, but it can be prevented. The spores that reach the soil after having been blown away by the wind during thrashing, and those that may in one way or another reach the manure heap are of no practical importance in this country in regard to infection. It is the spores carried on and with the seed grain that alone serve to propagate the disease. If these can be removed, killed, or prevented from germinating, without serious injury to the vitality of the grain, the resulting crop will be smut-free. For this purpose contaminated grain should be pickled with an appropriate fungicide.

Of course, grain from a healthy crop of barley, free from Covered Smut, does not require to be pickled, unless it has in some accidental way become contaminated with spores, as, for example, by having been thrashed in a contaminated machine or stored in contaminated sacks. Where there may be any doubt as to whether seed barley is contaminated or not, a sample should be submitted to an expert for microscopical examination, or to the Official Seed Testing Station, Cambridge, as mentioned in connexion with Bunt of wheat (see p. 5).

The most satisfactory fungicide for pickling barley is formalin. For use it requires to be diluted with water, and a suitable dilution is 1 pint of formalin to 40 gal. of water, or ½ fluid oz. (1 tablespoonful) per gal. A much stronger solution than this is apt to injure the vitality of the grain, whilst a much weaker one would not completely disinfect it.

The seed may either be dipped in the solution or be sprinkled or sprayed with it. If dipped, the seed, when in the tub, should be well stirred, so that every individual grain may become thoroughly wetted; and any fragments of smutted material that may float to the surface should be skimmed off and destroyed. The time of dipping should not exceed about 15 minutes. The solution should then be removed and the grain, after thorough draining, placed in a heap on a clean floor and covered with sacks, previously wetted with the formalin solution. After remaining covered for four hours, the grain should be spread out in a thin layer in order to dry as rapidly as possible.

For sprinkling or spraying, the grain should be treated by the method described for Bunt of wheat on p. 5.

Copper sulphate solution is not to be recommended for pickling seed barley, unless the grain is subsequently dusted over with powdered lime. Sufficient information has not yet been accumulated as to the practical efficacy or otherwise of a powder, such as copper carbonate, for dry treatment of contaminated barley seed against Covered Smut. The evidence so far available seems to show that this method is less successful against this disease than against Bunt in wheat.

LOOSE SMUT OF BARLEY

This form of Smut* is not very common in this country and the losses caused by it are not so great as those due to Covered Smut. Like Covered Smut, it does not become evident until

* The fungus that causes Loose Smut of Barley is generally known as *Ustilago nuda*.

the ear emerges, when masses of black, soot-like, fungus spores are seen to have developed in place of healthy grains. An ear of barley affected with Loose Smut is illustrated in Fig. 5.

Contrary to what occurs in Covered Smut, the spore masses in Loose Smut, not being held together for any length of time by the remains of the skin of the grain or of the adhering chaffy scales, quickly begin to break up. The spores therefore are at once distributed far and wide by wind and other agencies. By harvest time, as a rule, most, if not all, of this Smut will have disappeared; consequently there will be little or no infective material remaining to contaminate the healthy grain during thrashing.

The spores of Loose Smut, then, are distributed at a time when healthy ears are in the flowering condition; that is, when the stigmas of the flowers are ready for the reception of pollen grains. The Smut-spores also reach these stigmas, and germinate there, and the branching germ-tubes quickly enter the incipient grains. This mode of entry of the parasite, therefore, differs entirely from the underground infection of the very young seedling that occurs in Covered Smut.* It is *flower infection* as contrasted with *seedling infection*.

The entry of the smut fungus into the incipient grain does not interfere with the development of the latter; and an infected grain cannot be distinguished at sight from a healthy one. Only by somewhat laborious microscopical investigation can the presence of the parasite within the infected grain be detected.

When an infected grain is sown it germinates normally and produces what appears to be a perfectly healthy seedling. The growth of the fungus keeps pace with that of the barley plant within which it lives, the mycelium or spawn being localized mainly in the neighbourhood of the growing points. When the development of the ear begins, the lurking fungus assumes the upper hand, and, seizing the food allotted by the plant for grain development, converts it to its own use and produces the conspicuous masses of black spores in the ears.

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* This is generally believed to be the prevailing, if not the only mode, of natural infection. Infection in the seedling stage may also perhaps be possible; it has at any rate been secured artificially in a few varieties by contaminating barley grains, both when intact and when deprived of their pales, with the spores of Loose Smut and sowing them. If his occurs naturally, external disinfection of the grain should be a partial preventive of infection; there is a certain amount of evidence that this is the case.

Prevention of Loose Smut of Barley.—From what has been said it will be realized that, in this disease, infected seed contains the parasite within it, and for practical purposes it is impossible to diagnose its presence there.

Barley from a crop known to have been affected with Loose Smut is best not used for sowing purposes. If, however, such use is unavoidable the seed may be disinfected by a method of hot-water treatment similar to that employed in treating wheat infected with Loose Smut (see p. 9). Mere superficial treatment with a fungicide is, of course, of no use against internal infection. The essence of the treatment is to raise the temperature of the interior of the seed to a point high enough to kill the fungus mycelium located there, without at the same time injuring the vitality of the grain.

This ideal is not attained without considerable difficulty, and different workers have employed slightly different methods to secure the end in view. The temperature required is approximately 124° F. (51° C.) and the following is a method of operation that has been found to give satisfactory results.

The grain should first be placed in a basket or large sack and then steeped for about four hours in cold or lukewarm water. It should then be plunged into water at 120° F. (49° C.) for five minutes, and, finally, steeped for ten minutes in water at, or a little above, 124° F. and kept at that point, if necessary, by the addition of water at a higher temperature. Care must be taken that the temperature does not rise too high, for if 130° F. is reached, serious damage to the grain may ensue. If the sack or basket is moved to and fro in the water during the steeping process, uniform heating of the individual grains will be facilitated. After treatment, the grain should be spread out to dry as rapidly as possible, and then sown without any considerable delay.

COVERED AND LOOSE SMUTS OF OATS

Oats, like wheat and barley, are attacked by both a Covered and a Loose Smut.* The latter appears to be very much more common than the former in this country, but the two forms are not very readily distinguishable, and adequate data as to their relative prevalence here are not available. From the practical standpoint this matter is of no importance; for, contrary to what is the case in the Covered and Loose Smuts of wheat and barley, the two Smuts of oats do not differ from each other in

* Covered Smut of oats is caused by *Ustilago Kolleri*, Loose Smut by *U. Avenae*.

the way in which infection of the host occurs. This takes place in the seedling stage, and both Smuts may therefore be controlled by the pickling of the seed grain with an appropriate fungicide.

Smutted heads of oats are illustrated in Figs. 6 and 7. Both by distribution of the spores in the field and through subsequent handling during harvesting and thrashing operations, the seed oats become contaminated with Smut-spores, which adhere to the surface of the grain. The spores may also become lodged between the pales and the kernel. Here they germinate and produce resting mycelium, part of which may invade the outer tissues of these organs, but infection of the ensuing plant occurs, as stated above, in the seedling stage below ground, and the further development of the two oat Smuts also pursues a course similar to that followed by Bunt of wheat and Covered Smut of barley (see pp. 3 and 10).

Prevention of Oat Smuts.—Both Covered Smut and Loose Smut of oats can be prevented by suitable disinfection of the seed grain, and the most appropriate fungicide is formalin. The dilution used may be the same as that for Bunt in wheat and Covered Smut in barley, namely, 1 pint of 40-per cent. formalin in 40 gal. of water, but a stronger solution, viz., 1 pint in 20 gal., is not infrequently recommended and is perhaps preferable for oats. The seed grain should be steeped or sprinkled as already described on page 6, and afterwards covered with sacks for four hours. It should then be spread out in a thin layer to dry and afterwards sown with as little delay as possible.

A method of treatment that has gained considerable popularity in parts of the United States of America, and in which the grain at the conclusion of the treatment is dry enough to sow forthwith, is as follows:—The seed is placed in a heap on a clean floor, and is shovelled from this to form a second heap close by. Each shovelful of grain taken from the first heap receives a dose of formalin from a hand-sprayer as it lies on the shovel, and is then passed on to the second heap. The solution used is a concentrated one, made by the addition of 1 pint of water to 1 pint of 40-per cent. formalin. This amount (1 quart) is sufficient for about 50 bushels of seed. When the second heap is complete it is covered with sacks that have been wetted with the solution, and left to stand for five hours. It may then be put into new or disinfected sacks and drilled. Such seed, however, need not be sown immediately, for serious loss in germination is said not to occur on storage over a reasonable period. The chief disadvantage of the

method lies in the fact that the pungent formaldehyde gas arising from the concentrated solution used is apt to irritate the eyes, nose and throat of the workers, but this difficulty can largely be overcome if the operation is carried out in a well-aired place and if the sprayer-nozzle is kept close to the seed. The method appears to be worthy of trial in this country.

Copper sulphate (bluestone) solution is not recommended for use against the Smuts of oats, and the comparatively few trials that have so far been made with copper carbonate in powder or dust form have not given very satisfactory results with this cereal.

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